2.12 Physics Processes which Constrain Detector Performance

In general, the requirements of the NLC physics program do not put strong constraints on the detector design and performance. For most physics analyses, the performance of the detectors constructed for SLC and LEP would be quite sufficient. These detectors already include the basic requirements for the study of e^+e^- annihilation at high energy: calorimetry with good energy resolution, segmentation, and charged lepton identification; tracking with high momentum resolution, good forward angular acceptance and overall granularity; and excellent secondary vertex tagging. However, it is always interesting to consider advanced detectors with improved performance in one or another of these areas. In this section, we enumerate those physics topics which put exceptional or unusual demands on the detector and which might motivate a more advanced detector design.

A basic benchmark for detector performance is that given by standard model Higgs production in the all-hadronic mode: $e^+e^- \to Zh \to jj + b\overline{b}$. This sets a standard of hadronic energy resolution, angular coverage for high acceptance, and b-tagging efficiency. The recognition of the Z in its hadronic decay is required, more generally, for high-statistics branching ratio determinations for the Higgs boson.

For the Higgs boson of the Minimal Supersymmetric Model, it is possible for the Higgs boson to decay by mechanisms very different from those of the Standard Model. The interesting mode $e^+e^- \to hA \to b\overline{b}b\overline{b}$ places a premium on angular coverage and efficiency of b-tagging. More generally, it is important in this theory to be able to recognize the production of the Higgs boson in $e^+e^- \to Zh$ making as few assumptions as possible on the final state to which the Higgs decays. Such a model-independent search for the Higgs boson is possible if the Z can be reconstructed as an $\ell^+\ell^-$ pair superimposed on any reasonable Higgs boson final state. This analysis constrains the momentum resolution and two-track separation of the tracking device.

Finally, though the decay of the Higgs to $\gamma\gamma$ is rare, one might hope to observe the branching ratio for $h \to \gamma\gamma$ from the process $e^+e^- \to Zh$. This would demand a high-quality electromagnetic calorimeter, one with at least 3 times better resolution than is called for in our design [135].

For studies of supersymmetry, we have shown that calorimeter coverage down to $\cos\theta = 0.99$ is essential to reduce the standard model backgrounds to events with low visible energy. In addition, we have seen that the mass measurements for supersymmetric particles typically involve the measurement of sharp kinematic endpoints in lepton or jet energy distributions. The calorimetric energy resolution must be sufficiently good that the measurement of these endpoints is limited only by initial state radiation and beamstrahlung.

For studies of the W boson vertices in $e^+e^- \to W^+W^-$, it is necessary to completely reconstruct the final state kinematics by measurement of a lepton + 2 jet system. This would seems to demand high-quality tracking. However, it has been shown that the tracking requirements are less severe if kinematic fitting is used to determine the jet energies [85].

In the study of WW scattering, the reactions $e^+e^- \to \nu\overline{\nu}WW$ and $e^+e^- \to \nu\overline{\nu}ZZ$ give signatures for distinct models of a strongly interacting Higgs sector, as explained in Section 7.2. Thus, it is necessary to distinguish these processes experimentally. Because the event rate is rather small, it is necessary to rely on detection of W and Z in their hadronic decay modes. Thus, it is important that the calorimetric mass resolution for W and Z be sufficiently small that these particles can be distinguished on the basis of their masses. The analysis discussed in Section 7.2, which assumed a calorimeter resolution essentially the same as that of our model detector, found and incorporated a probability of about 10% for confusing each W for a Z or vice versa. In addition, this analysis requires good forward coverage for high-energy electrons and positrons, to remove background from the processes $e^+e^- \to e^+e^-W^+W^-$ and $e^+e^- \to e\nu WZ$ which are induced by virtual photons.

Finally, we note that the study of the top quark threshold is affected by the energy spread of the e^+e^- collisions, which is determined by the accelerator design. For this study to be carried out optimally, the beam energy spread from beamstrahlung should be kept to the level of initial state radation, about 3%, and the intrinsic beam energy spread of the accelerator should be kept to 0.1%. These requirements are quite reasonable for the machine design discussed in Chapter 3. In addition, since the differential luminosity spectrum depends on the beam parameters, it is necessary to measure this directly. This requires the measurement of acollinearity angles in small-angle Bhabha scattering to better than 1 mrad for $\theta \sim 200$–500 mrad. The detector design in Section 11 includes an appropriate electromagnetic shower detector placed inside the synchrotron radiation mask.